

Electromagnetic Propagation

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LONG TERM GOALS

Develop electromagnetic propagation models for use in operational or engineering propagation assessment systems.

OBJECTIVES

Develop an advanced unified hybrid radio propagation model based on parabolic equation and ray-optics methods for both surface-based and airborne applications. This model is named the Advanced Propagation Model (APM) and is the model used in the Advanced Refractive Effects Prediction System (AREPS). Resolve differences between current techniques used to model propagation effects under rough surface and strong ducting conditions.

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APPROACH

We develop parabolic equation, ray optics, waveguide, and other models as necessary to produce both accurate and efficient models to be used in propagation assessment systems. In many cases we can use variations of existing models to achieve this goal, but sometimes completely new models are necessary. Once developed, these models are compared to other models and to experimentally collected propagation data for verification of accuracy. We stay abreast of other researchers' newest models by reading current literature, participating in propagation workshops, and attending conferences as appropriate. There is a strong international exchange of ideas and techniques in this area, as some important work is performed outside of the USA. This project is divided into two tasks: (1) Propagation over Terrain, and (2) Rough Surface Effects.

WORK COMPLETED

PROPAGATION OVER TERRAIN

We implemented a rough sea surface model within APM based on the mixed Fourier Transform algorithm developed by Kuttler and Dockery (JHU/APL). APM Version 1.22 now accounts for rough sea surface effects and was transitioned into AREPS 2.0.

Research continued into applying PE techniques at EO frequencies and analyzing infrared transmission data collected during the Nov. '96 EOPACE IOP. FEL/TNO is also involved in analyzing aerosol measurements taken during this IOP to better provide aerosol data at 10 minute intervals (corresponding to bulk meteorological measurement time intervals) in order to have a complete time series of transmission predictions including refractive effects.

Work began on incorporating a terrain clutter model in APM for use in simulations for inferring refractivity from land clutter. This is start-up work for the Refractivity Test Bed task. Preliminary results show favorable comparisons between "real" and inferred refractivity profiles.

ROUGH SURFACE EFFECTS

Digital data were received from FEL/TNO for the 1988 propagation measurements in the North Sea at 10.5 and 35 GHz. These data were analyzed and results were presented at URSI in January 1999. The analysis of all previous experimental data indicates that sea roughness is altering the strength of the evaporation duct.

The Wallops Island 1994 MPMS data were reanalyzed and placed into a convenient time series format by NSWCDD and delivered to SSC San Diego on 1 April 99. These data were then analyzed for evaporation duct and rough surface effects. Although modeled and observed losses matched very well, suitable rough surface effects were not observed during the entire observation period. A summary of the rough surface evaporation duct models compared to previous experimental data was presented at the Progress in Electromagnetics Research Symposium (PIERS) in March. A draft technical report "Rough Surface Propagation Effects during the Wallops Island 1994 MPMS Experiment" was prepared and forwarded to NSWCDD for comments. This report concludes that only very weak rough surface propagation effects were observed during the experiment. A paper "Evaporation Duct Propagation and Near-Grazing Angle Scattering from a Rough Sea" was presented at International Geoscience and

Remote Sensing Symposium (IGARSS) in July. This paper concludes that sea surface roughness is modifying the vertical refractivity profile and reducing the strength of the evaporation duct.

A revised test plan was prepared for the Rough Evaporation Duct (RED) experiment in Hawaii in summer 2001 and a planning trip for RED including an official visit to the Marine Corps Base Hawaii was conducted to coordinate the RED operation. In addition, much of the radio equipment needed for RED was ordered during this period. Researchers from the University of California at Irvine (Dr. Carl Friehe), Woods Hole Oceanographic Institution (Dr. Jim Edson), the Physics and Electronics Laboratory of the Netherlands (FEL/TNO) have expressed interest in supporting the RED experiment. One major change to previous plans has been the inclusion of the R/P FLIP, which will be moored some 10 km offshore of Oahu, HI and will serve as the primary meteorological data collection platform. Figure 1 outlines the proposed RF and EO paths.

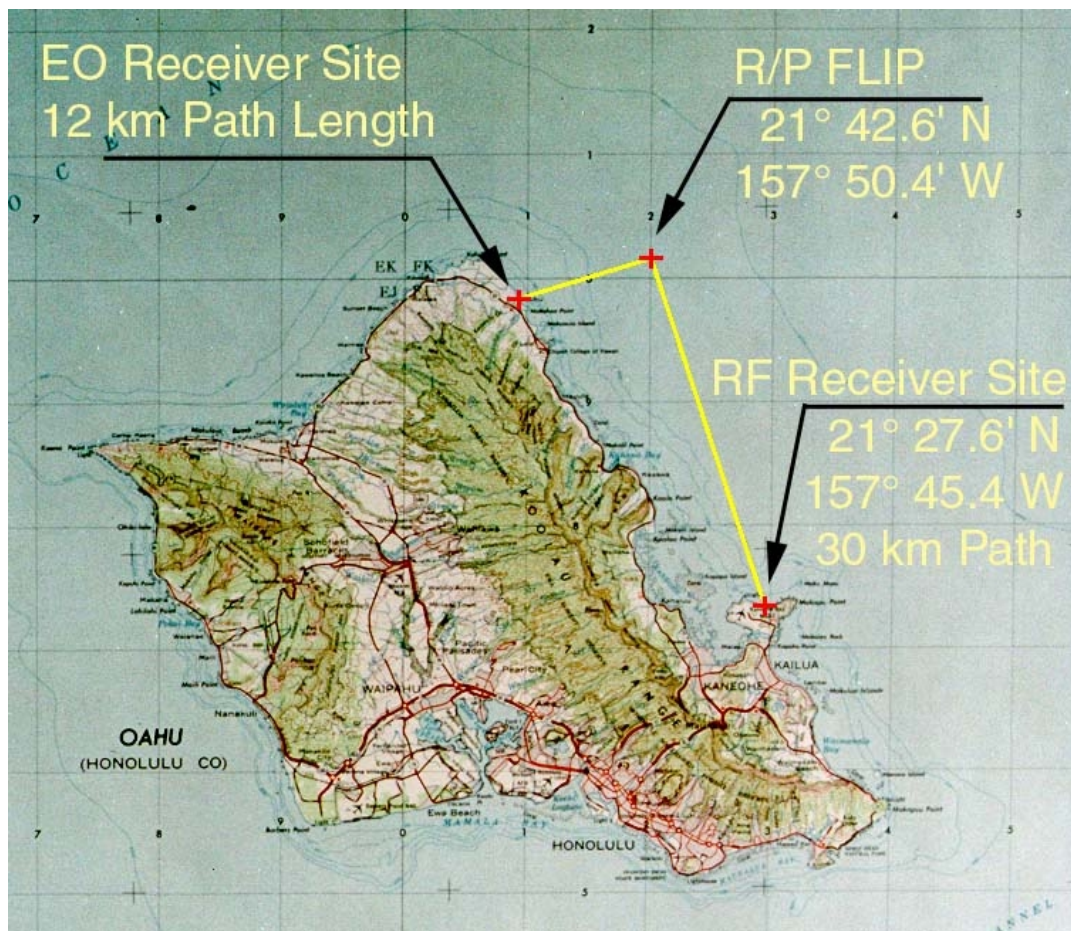


Figure 1. Proposed paths for the RED experiment.

NPS initiated work on the treatment of propagation over rough surfaces using a full-wave extended integral equation. The extended integral equation becomes unstable when either the frequency is large or when the surface becomes very rough. We used Tikhonov's regularization technique to stabilize the equation and hence extend its applicability to higher frequencies and/or rougher surfaces. However, the

approach suffered from the drawback that the regularization parameter could not be chosen appropriately all of the time. A single criterion for choosing the regularization parameter could not be established. Hence the approach was not pursued anymore. Using the Volterra integral equation approach, we have started to look at forward propagation over rough sea at low grazing angles. This treatment is directly applicable to the parabolic equation. The goal is to be able to treat surfaces having large undulations such as encountered in propagation over the ocean surface. The sea surface is described by the Pierson-Moskowitz spectrum. The model was first validated at 500 MHz by comparing with results available in the literature. Equivalent admittance values were generated at 3 GHz for wind speeds in the range 5 m/s–20 m/s. The numerical procedure was considerably slowed when applied at 10 GHz. Studies are being carried out to remedy this situation. This work was presented at the 1999 URSI General Assembly in Toronto, Canada in August 1999.

RESULTS

PROPAGATION OVER TERRAIN

The primary result of this task is the development of the Advanced Propagation Model. This model is now very robust and includes a very complete set of features. It is already being widely used by fleet operational personnel and others in the Advanced Refractive Effects Prediction System.

One major hindrance in the analysis of IR transmission data with PE techniques is the weakness of the LKB (Liu, Katsaros, Businger, *J. Atmos. Sci.*, 1979) surface layer model to properly compute refractivity profiles for strongly stable conditions, which were a common occurrence during the Nov '96 EOPACE IOP.

ROUGH SURFACE EFFECTS

The current rough sea surface models in use by the majority of researchers in this area have still not been validated. These models include the SSC San Diego waveguide model MLAYER and the hybrid model APM, the JHU/APL PE model TEMPER, and the British hybrid model TERPEM. All are based on the Miller-Brown rough surface reflection coefficient model and some method of determining the surface grazing angle. MLAYER is considered the most mathematically rigorous of these methods since the eigen angle for each mode is directly related to grazing angle. MLAYER was used in all the analyses described above, but the findings should hold for the other models as well.

Altogether, four different data sets were analyzed: Greek Islands, Catalina to San Clemente, The Netherlands, Wallops Island. For the 1994 Wallops Island MPMS data, modeled and observed losses matched very well, however, suitable rough surface effects were not observed during the entire observation period. Only the 1988 experiment in The Netherlands appears to contain periods of both strong ducting and high wind speeds. Based on the analysis of these data, along with the other three data sets mentioned, it is concluded that sea surface roughness is modifying the vertical refractivity profile and reducing the strength of the evaporation duct.

IMPACT/APPLICATIONS

The goal of this work is to produce the best possible hybrid radio propagation model for incorporation into U.S. Navy assessment systems. Current plans call for APM to be the single model for all applications. As APM is developed it will be properly documented for delivery to the Oceanographic

and Atmospheric Master Library (OAML), from which it will be available for incorporation into Navy assessment systems. The extension of APM to account for rough surfaces will improve operational assessments and also provides modeling support for a related project pursuing the concept of extracting refractivity profile information from radar clutter returns.

TRANSITIONS

APM Version 1.22 now accounts for rough sea surface effects and was transitioned into the Tactical EM/EO Propagation Models Project (PE 0603207N) under PMW 185.

RELATED PROJECTS

This project is closely related to the synoptic and mesoscale numerical analysis and prediction projects pursued by NRL Monterey and the Coastal Variability Analysis, Measurement, and Prediction (COVAMP) project which pursue providing the refractivity inputs for APM. This project is also related to the Remote Refractivity Sensing project under ONR 321SI in providing fast-running, high-fidelity forward propagation modeling used in the RRS inference techniques. The transition target for this project is the Tactical EM/EO Propagation Models task under PMW 185 and the Oceanographic and Atmospheric Master Library. Tri service coordination is conducted under the Technology Area Review and Assessment.

PUBLICATIONS

H.V. Hitney, "10.5 and 35GHz Propagation In the North Sea", National Radio Science Meeting, *URSI*, 4-8 Jan 1999, pp. 139.

H.V. Hitney, "Rough Sea Effects on Microwave Propagation in the Evaporation Duct," *PIERS*, 22-26 March 1999.

H.V. Hitney, "Evaporation Duct Propagation and Near-Grazing Angle Scattering from a Rough Sea," *IGARSS*, 28 June –2 July 1999.

R. Janaswamy and M. Motta, "Low Grazing Angle Forward Propagation Over Rough Surfaces Using Parabolic Equation," 26th General Assembly *URSI*, Toronto, Canada, 13-21 August 1999.

M.J. Motta, "Equivalent Impedance of Rough Surface at Low Grazing Angles," NPS Master's Thesis, 80 pp., September 1999